Current Research (2001) Newfoundland Department of Mines and Energy
Geological Survey, Report 2001-1, pages 89-103

STRUCTURAL SEQUENCE AND STRATIGRAPHIC ORDER OF THE ORDOVICIAN WILD BIGHT GROUP IN THE SEAL BAY BROOK–WEST ARM BROOK AREA (NTS MAP AREA 2E/5), NORTH-CENTRAL NEWFOUNDLAND

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ABSTRACT

In the Seal Bay Brook–West Arm Brook area, the revision of the lithostratigraphic order of the Early–Middle Ordovician Wild Bight Group, results in an unnamed unit of mineralized felsic volcanic rocks being placed at the bottom of the group, below the turbidite and basalt intervals in each of the succeeding Omega Point, Sparrow Cove and lower Pennys Brook formations. The structural sequence of rocks is indicative of a tectonic stacking of the original Wild Bight Group succession in a series of large thrusts and nappes. In particular, these produced a regional repetition of the youngest stratigraphic unit, the Pennys Brook Formation. Base-metal prospective tracts of lower Wild Bight Group rocks are structurally detached from strata in the middle and upper parts of the group, and are preferentially located near the arcuate sole thrust of an imbricate fault zone within a regional horseshoe-shaped thrust stack.

INTRODUCTION

Each of the original constituent formations of the Ordovician Wild Bight Group (Dean, 1978; Figure 1) were mapped in a regional periclinal fold structure termed the Seal Bay Anticline (Dean, 1977). South of Seal Bay, these formations were shown to be disposed about a generally southward-plunging anticline, and the present structural sequence of rock units seen in the anticline's core and across its fold limbs revealed the correct stratigraphic order of the five formations of the Wild Bight Group.

The simplified geological map of the Seal Bay Brook–West Arm Brook area presented here depicts the anticline, located near Seal Bay Bottom and Seal Bay Brook, as being regionally discontinuous, having been displaced along its axial trace by broadly contemporaneous faults (Figure 2). Thus, this southeast- and southwest-plunging anticlinal fold nappe is merely one of several large fault-bounded folds that control disposition of various intervals in the stratigraphic succession of the Wild Bight Group.

Throughout the study area, bedding-parallel thrust or reverse faults cause omission or repetition of one or more formations of the Wild Bight Group (Figure 2). Simple folded successions face stratigraphically westward or eastward and comprise what are essentially intact thrust sheets, bounded by these early formed contraction faults. In the study area, several regional thrust faults merge, and thereby structurally isolate at least five separate tectonic panels of the Wild Bight Group. Each panel preserves a different stratigraphic range, although none of them contain a stratigraphically continuous succession from the lowest to the highest formation. The west-facing and east-facing tectonic panels alternate in a way that is incompatible with the presence of a single, regional, south-plunging anticline in the Seal Bay Brook–West Arm Brook area (Figure 2).

STRATIGRAPHIC ORDER OF ROCK UNITS

Volcanic and sedimentary rocks belonging to the lower and middle parts of the Wild Bight Group are well exposed in several areas. Farther west, where the Wild Bight Group is observed to conformably underlie the Middle–Late Ordovician Shoal Arm Formation (Figure 1), the erosion level is completely within the Pennys Brook Formation, the most widespread and stratigraphically highest unit (O'Brien, 1997, 2000). In one locality east of the map area, the uppermost part of the group is known to be late Middle Ordovician (O'Brien, 1992). Whereas the exclusively volcanic units of the lower Wild Bight Group are probably Early Ordovician, most of the volcanosedimentary strata of the middle Wild Bight Group are probably Early to Middle Ordovician (*cf*. MacLachlan, 1998).

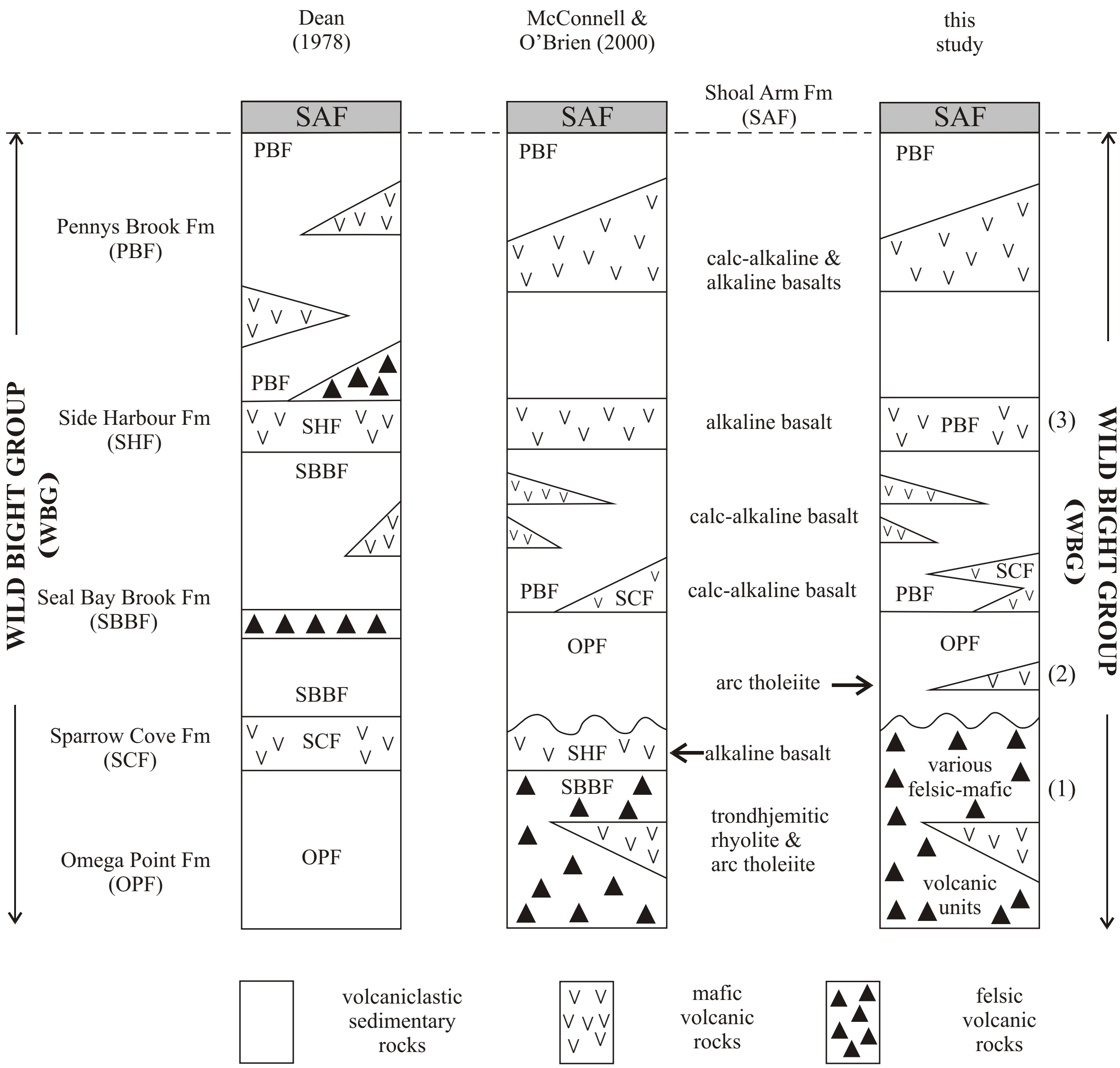

Figure 1. *Proposed stratigraphic column of the Wild Bight Group in the Seal Bay Brook–West Arm Brook area shown in relation to a simplified version of McConnell and O'Brien's (2000) map-unit log of the Badger Bay, Seal Bay and New Bay River regions, and Dean's (1978) stratigraphic analysis of the entire Wild Bight Group. Note that the writer regards the type area of the Seal Bay Brook Formation to be underlain by the rocks of the lower–upper Pennys Brook Formation (*see *Figure 2) and that the type area of the Side Harbour Formation is regarded to be mostly underlain by a volcanic rock lenticle belonging to the upper Pennys Brook Formation (*see *Figure 4).*

Notes (Numbers referenced to right column):

1) All units similar to MacLachlan's (1998) old WBG sequence near Glovers Harbour. Previously included in Dean's (1978) SBBF or lower PBF succession. Equivalent to McConnell and O'Brien's (2000) SBBF sequence in the Corner Point - Indian Cove area.

2) Previously included in Dean's (1978) SHF, upper SBBF or SCF units. Unseparated in the OPF succession of McConnell and O'Brien (2000).

3) Lenticle assigned to the SHF by Dean (1978) and McConnell and O'Brien (2000).

MIDDLE WILD BIGHT GROUP

The Omega Point, Sparrow Cove and Pennys Brook formations of Dean's (1978) Wild Bight Group are well exposed and widely distributed in the Seal Bay Brook–West Arm Brook area. The lower Omega Point Formation is predominantly composed of red conglomerate, olistostrome, chert and iron formation. A distinctive, variably thick, dark-grey argillite subunit is commonly found low in this succession. It is host to debris-flow deposits, especially where a graphitic or carbonaceous shale is interbedded with the grey argillite. In the Long Pond area, the Omega Point Formation also contains several pillowed basalt lenticles; elsewhere, such basalts occur in slump sheets along with the enclosing redbeds. The upper part of the formation is dominated by red and green siltstone turbidites.

The succeeding Sparrow Cove Formation is laterally discontinuous. Where present, it is mostly made up of pillow lavas, pillow breccias and basalt flows. In many but not all locations, these volcanic rocks are separated by minor intervals of thin-bedded sandstone turbidite that display delicate parallel-lamination, or have small ripple marks on the bedding planes. However, Sparrow Cove mafic volcanic rocks are also locally observed to infill scours that are at least 5 m deep in the host tuffaceous wackes. Massive rip-up clasts of such green epiclastic strata are enclosed within these lava flows.

Green and grey, mottled, concretionary, volcaniclastic turbidites comprise most of the overlying Pennys Brook Formation. The sedimentary rocks in this formation form cyclothemic thinning-upward and fining-upward sequences, and appear to thicken eastward. A typical Pennys Brook cycle would begin with a sharp-based conglomeratic to pebbly wacke, pass upward into a massive tuffaceous wacke, and end with a gradationally interbedded or sharp-based sequence of slump-folded sandstone turbidite and banded siliceous argillite. The sedimentary rocks of the Pennys Brook Formation are intercalated with several, stratigraphically discrete, laterally discontinuous lenticles of pillow lava and basalt breccia (Figure 1). Most volcanic lenticles in the Pennys Brook Formation are associated with spectacular olistostromes carrying volcanic and sedimentary olistoliths.

The Pennys Brook Formation lacks distinctive marker horizons; however, a crude stratigraphic position can be generally estimated in the field by recognizing the differences in the composition of the cyclic sequences in the lower and upper parts of the unit. In the lower Pennys Brook Formation, the basal wackes are graded over thicker stratigraphic intervals and they contain more boulders and cobbles than they do pebble-sized clasts. They also possess polymictic clasts of limestone, granite and altered volcanic rocks at the expense of sedimentary intraclasts derived from other parts of the Pennys Brook Formation. In this regard, the lower Pennys Brook Formation is similar to the Charles Brook and Saltwater Pond members of the New Bay Formation of the Exploits Group (O'Brien *et al.*, 1997).

In the upper Pennys Brook Formation, the tuffaceous wackes in the intermediate part of the cycle predominate over the basal conglomeratic wackes. Moreover, proceeding up-section, these tuffaceous wackes are represented by very thick, unstratified, monolithic packstones composed almost entirely of a few types of variably textured basalt clasts. Most of the vesicular mafic volcanic clasts are similar to the flows observed in the intercalated basalt lenticles. Felsic volcanic clasts are absent, although they do form a minor component of the volcanic clasts seen in the massive tuffaceous wackes lower in the succession. The uppermost Pennys Brook Formation is mostly dominated by upper cycle sequences composed of the banded siliceous argillites and the thin-bedded sandstone turbidites, and it is very similar to the Strong Island Chert of the Exploits Group (Dec *et al.*, 1992).

The marine redbeds of the Omega Point Formation are gradationally overlain by the green turbidites of the Pennys Brook Formation in each of the five tectonic panels of the Wild Bight Group (Figure 2). In some places, the basalt flows of the Sparrow Cove Formation separate the sedimentary rocks of the Omega Point and Pennys Brook formations (Figure 1). In other localities, the Sparrow Cove Formation occurs as a thin basalt lenticle persistently located in the lowest part of the Pennys Brook Formation. The regional geology of the Seal Bay Brook–West Arm Brook area is illustrated, in essence, by a map depicting the stratigraphic boundaries of the upper Omega Point Formation, the Sparrow Cove Formation and the lower Pennys Brook Formation (Figure 2).

Large gabbro sills, having strong aeromagnetic expressions, are widely developed throughout the Seal Bay Brook–West Arm Brook area. Present throughout the entire stratigraphic range of the Wild Bight Group, these pretectonic intrusions are preferentially emplaced into the well-stratified parts of the Omega Point Formation and the middle to upper Pennys Brook Formation. In areas of poor exposure, they are particularly useful as local structural markers within individual tectonic panels of the Wild Bight Group. Correlated with the Gummy Brook Gabbro in the western Wild Bight Group (O'Brien, 1997, 2000) and the Thwart Island Gabbro in the eastern Exploits Group (O'Brien *et al.*, 1997), they probably belong to a regional arc-rift-related suite of late Middle Ordovician laccoliths.

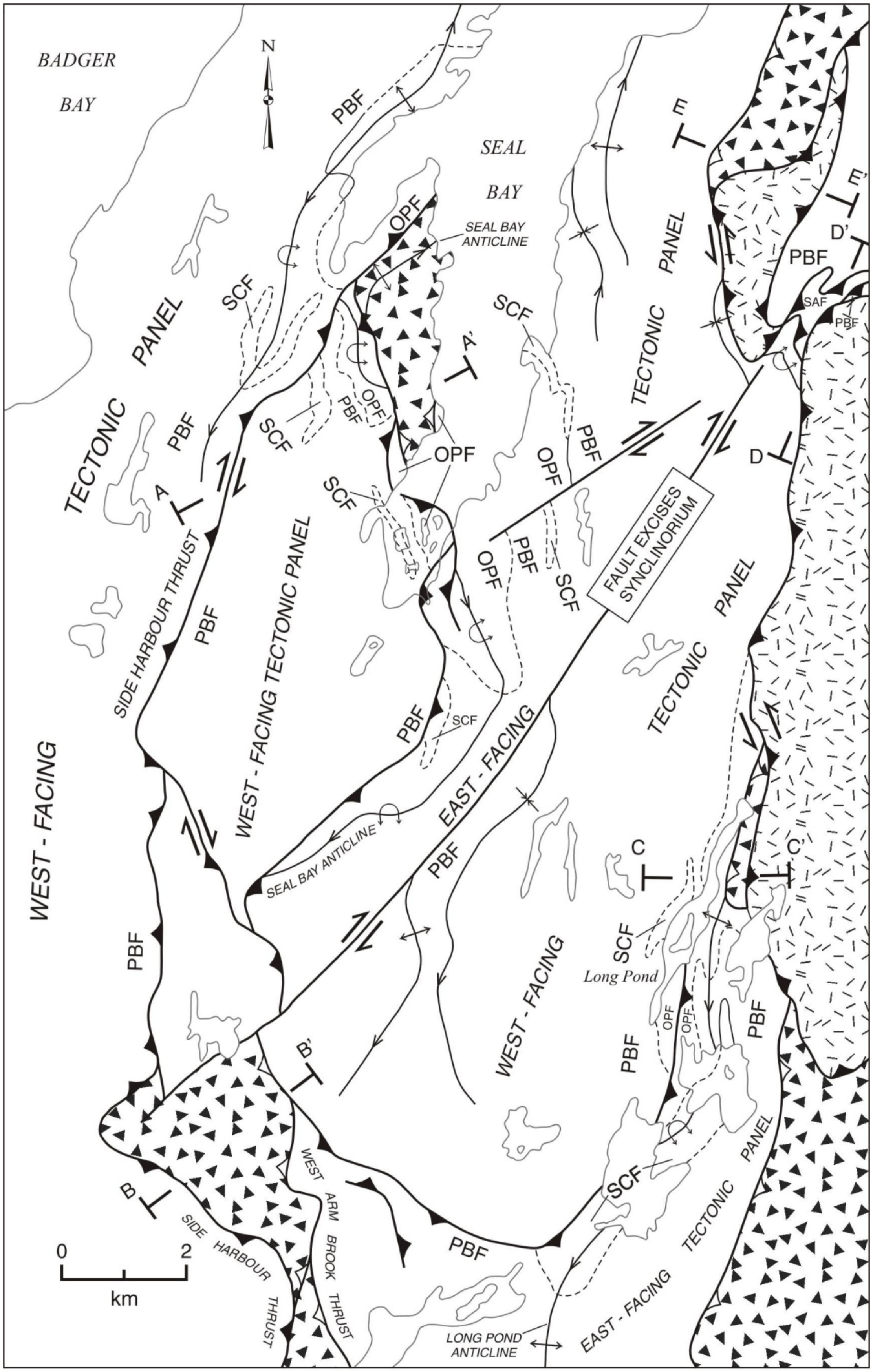

Figure 2. *Caption on opposite page.*

Figure 2. (opposite page) *Simplified geological map of the Seal Bay Brook–West Arm Brook area, emphasizing the regional structure and stratigraphy of the Wild Bight Group (WBG). Dashed lines illustrate the stratigraphic boundaries of the upper Omega Point (OPF), the Sparrow Cove (SCF) and the lower Pennys Brook (PBF) formations of the WBG (*see *Figure 1). Patterned areas are underlain by felsic–mafic volcanic rocks that are thought to have originally been stratigraphically overlain by OPF sedimentary rocks (and thus interpreted to comprise the lowest units of the WBG in Figure 1). Stippled areas are underlain by the South Lake Igneous Complex (felsic–mafic plutonic rocks equivalent in age to the sub-OPF volcanic rocks). Note that the oldest WBG rocks occur sporadically along the arcuate trace of a major thrust and reverse fault that dips westward, southward and eastward in the area surveyed.*

Stratigraphic Revisions

Although Dean (1978) had correctly placed the Sparrow Cove Formation stratigraphically above the Omega Point Formation, he had also recognized two other younger formations below his uppermost unit, the Pennys Brook Formation (Figure 1). In ascending stratigraphic order, Dean (1978) named the intervening formations the Seal Bay Brook Formation and the Side Harbour Formation.

The basalt-dominated sequence of Dean's (1978) Side Harbour Formation was pivotal in arguments employed to originally establish a stratigraphic column for the Wild Bight Group. First, this formation was partially coincident with one of the strongest and most regionally extensive aeromagnetic anomalies in the eastern part of the Wild Bight Group. Hence, the unit was deemed to outline the western limb and core of the Seal Bay Anticline, about 6 km down-plunge from the top of the Omega Point Formation. Second, Dean's (1978) Side Harbour Formation could be mapped to underlie, not only the turbidites and basalts of his Pennys Brook Formation, but also the mineralized rhyolites at the Point Leamington massive sulphide deposit (Walker and Collins, 1988; Swinden and Jenner, 1992; MacVeigh, 2000).

Because the Wild Bight sequence, above the Omega Point and Sparrow Cove formations, stratigraphically underlay Dean's (1978) Side Harbour Formation near Seal Bay Brook, he assigned the map unit to the Seal Bay Brook Formation and placed it well below his Pennys Brook Formation. This concept was adopted by McConnell and O'Brien (2000), even though O'Brien (2000) had recognized Pennys Brook and Omega Point strata below the Seal Bay Brook Formation in this particular Wild Bight sequence. Dean (1977) included the felsic volcanic rocks exposed on the west side of Seal Bay Bottom (Figure 2) within his Seal Bay Brook Formation. However, rather than overlying the Omega Point Formation, McConnell and O'Brien (2000) reasoned that these same felsic volcanic rocks lay disconformably beneath the Omega Point Formation (Figure 1).

Based on geological mapping in the 2000 field season, the writer regards the type area of Dean's (1978) Seal Bay Brook Formation to be underlain by the sedimentary and volcanic rocks of the lower, middle and upper Pennys Brook Formation. Furthermore, the type area of the Side Harbour Formation is regarded to be mostly underlain by a volcanic rock lenticle belonging to the upper Pennys Brook Formation. Therefore, the well-known alkaline basalts in the Side Harbour Formation have been removed from McConnell and O'Brien's (2000) "lower" Wild Bight Group and placed instead in the "upper" Wild Bight Group (Figure 1). However, in certain places along its strike, Dean's (1978) Side Harbour Formation is probably a tectonically composite unit, as it includes mafic volcanic rocks presently or previously assigned to the Omega Point Formation, the Sparrow Cove Formation and several lenticles of the Pennys Brook Formation.

LOWER WILD BIGHT GROUP

The felsic–mafic volcanic rocks of the lower Wild Bight Group and the sedimentary rocks of the Omega Point Formation are observed to be separated by an erosional disconformity (Figure 1) in one locality [E602800 N5474150] about 900 m north of Hook Point (O'Brien, 2000). Although not illustrated in Figure 2, this disconformity is located near the structural base of the east-facing tectonic panel that contains the Seal Bay Anticline. Here, the primary stratigraphic contact is fortuitously preserved on the northeast-trending (refolded) limb of an early formed anticlinal nappe.

At most of its other geological boundaries, lower Wild Bight Group volcanic rocks are faulted against a variety of units belonging to the middle or the upper Wild Bight Group. Although the original depositional boundary of the lower Wild Bight sequence is displaced by a thrust fault in the east-facing tectonic panel containing the Long Pond Anticline (Figure 2), the tectonically adjacent section of the Omega Point Formation includes the lower red conglomerate and the debrite-bearing grey argillite subunit. Here, and at Hook Point, hematized quartz-feldspar porphyries, which cut lower Wild Bight Group rhyolites, are very similar in appearance to the hematized quartz-feldspar porphyry cobbles observed in the red conglomerate beds of the Omega Point Formation.

Some of the oldest and youngest rocks of the South Lake Igneous Complex occur in the Seal Bay Brook–West Arm Brook area, although only a small part of the entire complex is represented (O'Brien, 1992; MacLachlan, 1999). Layered gabbros and flaser-banded metagabbros are well exposed in the area surveyed and are observed to be intruded by swarms of sheeted mafic dykes. All of these rocks are found as enclaves in a widespread, medium-grained, blue-quartz tonalite. Minor amounts of hornblende diorite and gabbro pegmatite are associated with the variably sheared tonalite intrusions. A narrow belt of metagabbro, which is injected by several sheeted bodies of quartz- feldspar porphyry, is host to numerous small gossan zones near the north end of Long Pond.

In most places, the lower Wild Bight Group volcanic rocks are thrust faulted against the broadly age-equivalent plutonic rocks of the South Lake Igneous Complex. However, in one locality northeast of Kerry Pond (MacLachlan, 1999), a metre-thick diabase dyke is seen to separate a pyritic blue-quartz tonalite of the South Lake Igneous Complex from a chloritic basalt of the lower Wild Bight Group.

Lithology

The five outcrop areas of lower Wild Bight Group rocks recognized in the Seal Bay Brook–West Arm Brook area (Figure 2) all contain interstratified rhyolite and basalt flows crosscut by minor felsic porphyry and diabase intrusions. However, because none of these fault-bounded tracts contain an identical lithotectonic sequence, they may not represent an exact duplication of the same paleogeographic region of the Early Ordovician volcanic island arc.

In the Long Pond area (C-C' in Figure 2), the felsic extrusive rocks are dominantly light-grey rhyolite breccia and pyritic felsic tuff; whereas, the felsic intrusive rocks include hematite-rich quartz-feldspar porphyries and rare, purplish-red rhyolite dykes. Where silicified, the porphyry is locally injected by red chert veinlets. Dark-green pillow breccia and light-green basalt flows dominate over a mixed mafic–felsic volcanic breccia in the Long Pond area.

The Little Lewis Lake tract of the lower Wild Bight Group is mainly underlain by mafic volcanic rocks. However, due to its small outcrop area, it has not been separated from a structurally overlying sequence of the Omega Point Formation in Figure 2. The Little Lewis Lake tract contains a distinctive red basalt breccia containing jasper disseminations; some slump-folded beds of grey argillite and carbonaceous shale partially enclose blocks of this basalt breccia. A light-green to dark-green vesicular basalt, which is commonly epidotized, chloritized and intruded by abundant pyritic quartz stringers, alternates with the zones of red volcanic breccia.

Interstratified mafic and subordinate felsic volcanic rocks also occur southeast of Kerry Lake and the South Lake Igneous Complex (Figure 2). They are presumed to be an extension of the Nanny Bag Lake belt of lower Wild Bight Group volcanic rocks (MacLachlan, 1999) that outcrop to the immediate east of the area surveyed (Dean, 1977; MacLachlan and O'Brien, 1998). Dark-green chloritic pillowed basalt and light-green, epidote-rich, pyritic, net-veined basalt are ubiquitous; whereas, variegated, red and green, vesicular pillow lavas are developed in more restricted areas. In the Kerry Lake region, light-grey, well-banded, flow-folded rhyolite bodies, which are intruded by diabase dykes, are interlayered with minor basalt flows.

In the lower Wild Bight Group tract west of Big Lewis Lake (B-B' in Figure 2), massive, dark-grey and dark-green basalt flows contain minor amounts of pillow breccia that grade to tuffaceous wacke. Rare intervals of mafic tectonite are also observed in this fault-bounded panel near the West Arm Brook Thrust. This tract is considered to be an extension of the New Bay Pond belt of volcanic rocks (Swinden and Jenner, 1992; Dickson, 2000). In the west, near the Point Leamington deposit, felsic–mafic crystal lithic tuff is found in association with light-green siliceous basalt breccia and dark-green pyritic basalt flows. In this region, some debris-flow deposits illustrate silicified blocks of basalt breccia and relatively unaltered blocks of thinly bedded grey argillite.

Felsic volcanic rocks dominate the Indian Cove–Corner Point tract (A-A' in Figure 2), the best-exposed sequence of lower Wild Bight Group rocks in the Seal Bay Brook–West Arm Brook area. The main rock types are purplish-red rhyolite breccia, light-pink, flow-banded hematitic rhyolite and a light-grey, pyritic, rhyolite-dominant volcanic breccia. A conspicuous mixed mafic–felsic volcanic breccia has outsized basalt bombs and silicified flow-banded rhyolite blocks. Light-green, quartz-phyric crystal tuff comprises a small part of this sequence. Minor bodies of quartz-feldspar porphyry and purplish-red rhyolite dykes intrude all of the above felsic rocks. The interstratified mafic volcanic rocks of the Indian Cove–Corner Point tract are mostly composed of dark-green pillowed basalt and light-green basalt breccia that are intruded by diorite sills and diabase dykes.

Stratigraphic Revision

Dean (1977) assigned the felsic–mafic volcanic tracts shown in Figure 2 to his Seal Bay Brook Formation in some places and his lower Pennys Brook Formation in others. Systematic geological surveying of the Seal Bay Brook–West Arm Brook area has confirmed that all of these map units are very similar to MacLachlan's (1998) "old WBG sequence" near Glovers Harbour (E-E' in Figure 2;

MacLachlan and Dunning, 1998a; MacLachlan and O'Brien, 1998) and are hereafter informally referred to as the Glovers Harbour volcanic rocks. These rocks are host to the Lockport massive sulphide deposit (Swinden, 1988; Butler, 1999).

STRUCTURAL SEQUENCE OF ROCK UNITS

The present structural sequence of lithological units in the Seal Bay Brook–West Arm Brook area does not reflect the original stratigraphic order of the Wild Bight Group. On the contrary, if one accepts that Dean's (1978) Side Harbour Formation and much of his Seal Bay Brook Formation are constituents of the Pennys Brook Formation, the regional stacking order of the Wild Bight Group points to a major structural repetition of the primary depositional sequence (e.g., B-B' in Figure 3).

The Ordovician Wild Bight Group comprises a large tripartite thrust stack in the Seal Bay Brook–West Arm Brook area. From top to bottom, the regional structural sequence is an upper Omega Point to upper Pennys Brook succession (the hanging-wall sequence), a structural collage of lower, middle and upper Wild Bight Group strata and two younger formations of the Exploits Subzone (the folded imbricate fault zone), and a sub-Omega Point to upper Pennys Brook succession (the footwall sequence).

The structurally lowest succession of the Pennys Brook Formation in the area surveyed is generally coincident with the outcrop of Dean's (1978) Seal Bay Brook Formation (Figure 2). These Pennys Brook turbidites are overlain by a laterally extensive basalt unit, originally named the Side Harbour Formation (Dean, 1978). Illustrated as the patterned volcanic unit in the footwall sequence of Figure 4, this unit has a preserved stratigraphic boundary on its lower contact but a thrust or reverse fault along the entire length of its upper contact. This structure is interpreted to be the sole thrust of the main imbricate fault zone.

GEOMETRY OF THE THRUST STACK

In the northeastern part of the area surveyed, the sole thrust of the imbricate zone can be traced along the western boundaries of thrust sheets that carry Early Ordovician rocks (Figures 2 and 3), such as the Glovers Harbour volcanic rocks (E-E') and the South Lake plutonic rocks (D-D'). Proceeding southward in the hanging-wall sequence, the sole thrust leaves the western boundary of the presumed Early Ordovician Long Pond volcanic rocks, ramps upward into the Omega Point Formation, cuts through the Sparrow Cove Formation and passes into the lower Pennys Brook Formation (*see* section C-C' in Figure 3). Northeast of Big Lewis Lake, the sole thrust is mapped to ramp upward into a hanging-wall sequence of presumed mid-upper Pennys Brook sedimentary and volcanic strata (Figure 2), which are emplaced above a footwall sequence that contains one of the highest preserved basalt lenticles in the upper Pennys Brook Formation.

The structurally highest thrust of the main imbricate zone is located southeast of Little Lewis Lake. It is the structure that separates an east-facing section of the Pennys Brook Formation from the South Lake Igneous Complex and the Nanny Bag Lake tract of the lower Wild Bight Group (Figure 2). The uppermost thrust can be traced from the southeasternmost part of the area to the northern end of Long Pond, where it coalesces with the sole thrust.

In the northwestern Seal Bay Brook–West Arm Brook area, the sole thrust is traced along the northwest boundary of the presumed Early Ordovician volcanic rocks of the Indian Cove–Corner Point tract (Figure 2). Proceeding southwestward in the footwall sequence, the sole thrust ramps upward into the Omega Point Formation, cuts through the Sparrow Cove Formation, and passes into the lower and middle parts of the Pennys Brook Formation (*see* section A-A' in Figure 3). At this locality, the sole thrust generally places older Pennys Brook strata in the upper west-facing panel of the Wild Bight Group above younger Pennys Brook strata in the lower west-facing panel (Figure 3). The lower thrust fault depicted in section A-A', which merges to the northwest with the upper thrust fault, is essentially a footwall splay of the more extensive sole thrust.

In the southwestern area surveyed, the structurally highest thrust of the imbricate fault zone is the structure that forms the structural top of the New Bay Pond tract of presumed Early Ordovician volcanic rocks (Figure 2). It also marks the structural base of the most extensive of the west-facing tectonic panels within the Wild Bight Group, the hanging-wall sequence of Figure 4. The uppermost thrust of the imbricate zone coalesces with the sole thrust to the north (Figure 2), where the structure has been referred to as the Side Harbour Fault (MacLachlan and O'Brien, 1998). The Side Harbour Fault is mapped to crosscut the lower depositional contact of an upper Pennys Brook basalt lenticle near Point A in Figure 2. Farther south, it becomes bed-parallel and remains within this volcanic horizon for at least 16 km along strike (Figure 4).

The stratigraphic separation across the sole thrust appears to be relatively small where the footwall sequence of the Pennys Brook Formation is overplated by the hanging-wall sequence of the Pennys Brook Formation (Figure 4). However, most of the Wild Bight Group appears to be missing across the base of the imbricate fault zone where, in

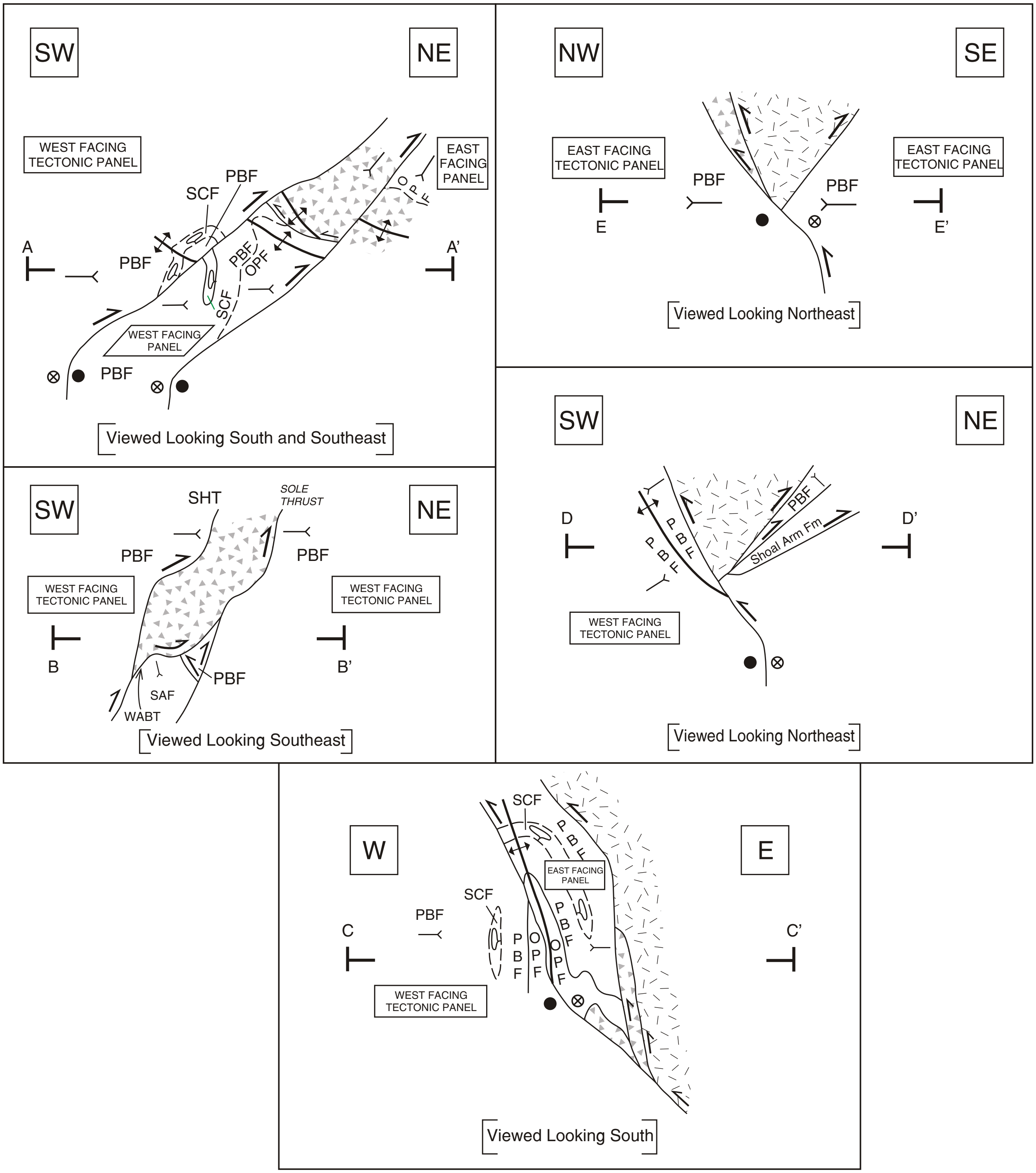

Figure 3. *Geological cross sections representative of the western, southern and eastern parts of the horseshoe-shaped thrust stack in the Seal Bay Brook–West Arm Brook area. Location of section lines A-A', B-B', C-C', D-D' and E-E' are shown in Figure 2; unit labels as for Figure 2. Note that these unbalanced schematic sections are not constructed to a vertical or horizontal scale, although directions of the down-plunge view of structures and rock units are indicated in each part of the thrust stack. A solid circle symbol adjacent to an oblique-slip thrust fault indicates that the tectonic panel so marked was displaced toward the viewer.*

places, Middle Ordovician strata of the Pennys Brook Formation at the top of the footwall sequence are directly overplated by Early Ordovician volcanic rocks from the stratigraphically lowest part of the group. West of Big Lewis Lake, the Sparrow Cove Formation and most, if not all, of the Omega Point Formation are missing across the highest thrust of the imbricate fault zone.

STACKED FOLD NAPPES

On the peninsula separating Seal Bay and Badger Bay, the upper Omega Point Formation, the Sparrow Cove Formation and the lower Pennys Brook Formation are disposed by an upright to northwesterly overturned anticline that plunges to the southwest (Figure 2). This regional anticline occurs above the northwest-dipping sole thrust at the structural base of the largest of the west-facing tectonic panels in the Wild Bight Group. Although the axial surface of this anticline has not been observed to be displaced by the adjacent Side Harbour thrust, this structure probably represents a fold nappe located in the upper part of the Seal Bay Brook–West Arm Brook thrust stack.

A major fold nappe within the lower part of the Seal Bay Brook–West Arm Brook thrust stack is well displayed to the south of Seal Bay. In the core of this anticlinal nappe, the sedimentary rocks of the Omega Point Formation plunge below the sedimentary rocks of the Pennys Brook Formation and west- and east-facing lenticles of overlying Sparrow Cove basalt (Figure 2). The eastern limb of this nappe, which is mainly right-way-up, preserves a stratigraphically continuous succession from the base of the Omega Point Formation to the middle part of the Pennys Brook Formation. Bounded by the overlying sole thrust and a dextral transcurrent fault, it forms an east-facing tectonic panel which varies from 2 to 4 km wide in plan view (Figure 2).

In contrast, the western limb of the Seal Bay Anticline is regionally overturned and tectonically thinned. In most places, this limb of the fold nappe is emplaced westward over the tectonically adjacent west-facing panel of the Wild Bight Group. A northeast- and southeast-dipping thrust fault occurs at the base of this refolded nappe (Figure 2). In the footwall sequence, this thrust displaces the grey argillite subunit and overlying red turbidites of the Omega Point Formation along the east shore of Seal Bay, cuts through the mafic volcanic rocks of the Sparrow Cove Formation south of the islands in Seal Bay Bottom, and ramps upward into the sedimentary strata of the lower–middle Pennys Brook Formation in the valley of Seal Bay Brook. A similar discordance is observed at the base of the hanging-wall sequence along the trace of the same thrust fault.

Back Thrusts and Fold Nappes

In the upper reaches of Seal Bay Brook, the sole thrust of the main imbricate fault zone has been mapped to truncate the generally east-dipping thrust at the base of the Seal Bay fold nappe (Figure 2). The truncation of northeast-dipping faults and allied fold structures by southwest-dipping D1 back thrusts also occurred near the base of the Seal Bay nappe about 8 km farther north (*see* cross section A-A' of Figure 3). There, a southwesterly overturned syncline in the footwall sequence of the Omega Point Formation and a faulted anticline in the adjacent hanging-wall sequence of lower Wild Bight Group felsic volcanic rocks probably relate to regional tectonic movements that predate the southwest-dipping back thrusts. Near the estuary of Seal Bay Brook, Omega Point Formation strata in the anticlinal core of the Seal Bay nappe are tectonically overlain by red cherts and LREE-depleted basalts (B. McConnell, personal communication, 2000). Lying structurally above a southwest-dipping back thrust, the overplated strata may belong to an older part of the Omega Point Formation or to the lower Wild Bight Group basalts seen in the Indian Cove–Corner Point tract farther northwest.

Synclinal Nappe below the Sole Thrust

A prominent dextral transcurrent fault, which trends northeastward for at least 10 km from upper Seal Bay Brook to Cramp Crazy Lake, postdates the regional folds and faults discussed in this paper. Because regional east-facing and regional west-facing panels of the Wild Bight Group are tectonically juxtaposed across this structure, the transcurrent fault must displace a major synclinorium in the Pennys Brook Formation (Figure 2). In this regard, the transcurrent fault is a tectonically equivalent, albeit younger, structure to the faults, that excised a regional synclinorium in the uppermost Pennys Brook Formation in the valley of Badger Bay Brook (O'Brien, 1998; *see* westernmost thrust faults in Figure 4).

In most places, the main imbricate fault zone formed above right-way-up beds in the upper or middle parts of the underlying Pennys Brook Formation. This is the case in the area lying to the west of the regional fault-excised synclinorium in the Wild Bight Group (Figure 2). However, along much of the eastern side of this arcuate fault zone, the Pennys Brook panel beneath the sole thrust faces stratigraphically northwestward on the southeast limb of a major syncline. Between D-D' and E-E', the core of this regional south-plunging syncline is probably located at the top of the footwall sequence, where the fold appears to be truncated by the sole thrust of the main imbricate fault zone (Figure 2).

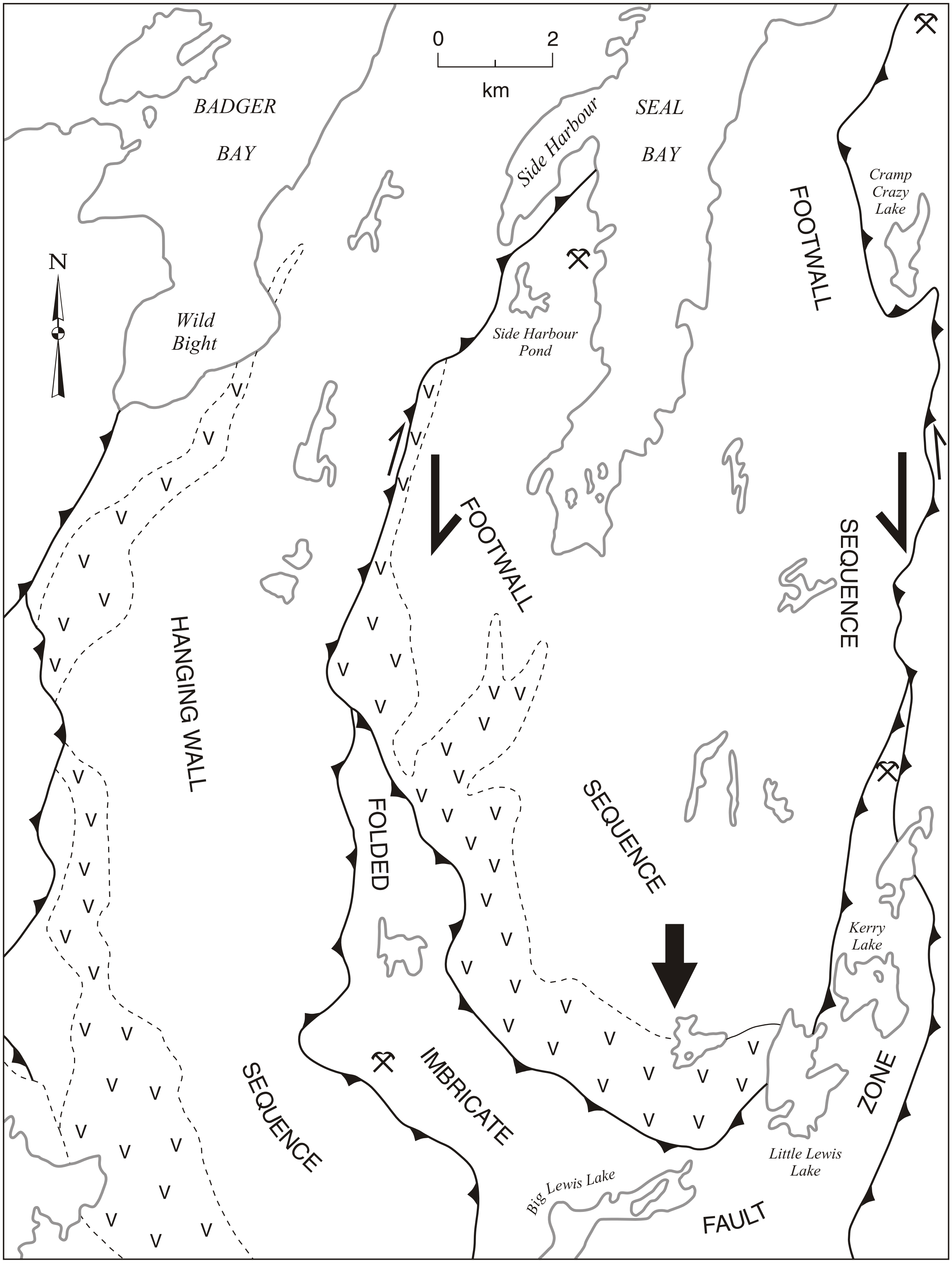

Figure 4. *Caption on opposite page.*

Figure 4. (opposite page) *Simplified tectonic map illustrating the main elements of the regional horseshoe-shaped thrust stack in the Seal Bay Brook–West Arm Brook area. In the southern part of the region, a folded imbricate fault zone is shown to separate right-way-up, hanging-wall and footwall sequences of the Pennys Brook Formation of the Wild Bight Group. Each sequence is interpreted to contain a broadly correlative volcanic lenticle (highlighted by a pattern), which occurs high in the PBF succession. In contrast, the folded imbricate fault zone contains rock units representative of the entire WBG stratigraphic range (*see *Figure 2). Note that the known base-metal prospects (depicted by symbols) are located, structurally, within the folded imbricate fault zone or in the immediate hanging-wall or footwall sequences. Arrows indicate the tectonic transport direction of the underplated footwall sequence.*

Thus, the regional curviplanar shape of this fault zone cannot be explained by the presence of a regional south-plunging anticline that affected all parts of the Seal Bay Brook–West Arm Brook thrust stack.

WEST ARM BROOK THRUST AND ALLIED BACK THRUSTS

The West Arm Brook Thrust of Swinden and Jenner (1992) occurs mostly within the main imbricate fault zone of the Seal Bay Brook–West Arm Brook thrust stack. A southwest-dipping thrust fault, it placed the New Bay Pond tract of the lower Wild Bight Group (Dickson, 2000) over a variety of younger rocks in the Wild Bight Group and succeeding units of the Exploits Subzone. Traced mainly by geophysical data (Swinden and Jenner, 1992; G. Kilfoil, personal communication, 2000), the footwall sequence is variably represented, from southeast to northwest, by the lower Gull Island Formation, the lower Shoal Arm Formation and the mid-upper Pennys Brook Formation (not separated in Figure 2; for unit descriptions, *see* O'Brien, 2000; for regional map pattern of units, *see* MacLachlan and O'Brien, 1998).

Northwest-trending reverse faults having a moderate northeast dip and a north-over-south sense of displacement also occur within the main imbricate fault zone in the southern part of the Seal Bay Brook–West Arm Brook area (Figure 2). They may predate the West Arm Brook Thrust and the other northwest-trending back thrusts in the imbricate stack. One such reverse fault affects a non-arc basalt lenticle from the Pennys Brook Formation (labelled PBF in B-B' in Figure 3), which lies tectonically adjacent to the highest preserved lenticle of Pennys Brook basalt in the footwall sequence of the sole thrust (Figure 4). Illustrated as the northeast-dipping thrust in B-B' in Figure 3, it is responsible for placing the older Pennys Brook Formation structurally above an inverted southwest-facing succession of the younger Shoal Arm Formation.

The West Arm Brook Thrust is postulated to coalesce with the sole thrust of the main imbricate fault zone near Point B' in Figure 2 (also *see* section B-B' in Figure 3) in the area northeast of the Point Leamington massive sulphide deposit. A splay from the West Arm Brook Thrust may possibly merge with the imbricate stack's uppermost Side Harbour thrust near the southwestern border of the map area (Figures 2 and 3). Thus, in the Seal Bay Brook area, the southeastward extension of the Side Harbour Fault lies structurally above the West Arm Brook Thrust.

ALTERATION OF ROCK UNITS

In the Seal Bay Brook–West Arm Brook area, secondary alteration minerals form variably coarse spotted aggregates that are typically associated with quartz and iron-carbonate veins. These pseudoporphyroblasts are preferentially developed in the sedimentary units of the Wild Bight Group, especially in fine-grained, silicified, volcaniclastic turbidites. They are most commonly encountered near basalt lenticle – sediment contacts or gabbro sill – sediment contacts. However, in many localities, mafic extrusive or intrusive rocks do not outcrop in the vicinity of the pseudoporphyroblast-bearing alteration zones. Moreover, in some places, unaltered mafic dykes crosscut these alteration zones and unaltered sedimentary rocks.

Rees (1999) determined that the green pseudoporphyroblasts in Pennys Brook turbidites are mainly pumpellyite–hydrogarnet–chlorite–epidote aggregates, whereas white pseudoporphyroblasts in such strata are mainly phengite–albite–quartz aggregates. Alteration minerals also occur disseminated throughout the sedimentary matrix. They include stilpnomelane, clinozoisite, sphene, calcite, apatite, hematite, pyrite and chalcopyrite. Orbicular cherts, chert nodules and porphyroblastic concretions also formed during the same fluid-controlled alteration events (Rees, 1999).

In the area surveyed, green and white pseudoporphyroblasts are most widespread in the tectonic panel containing the Seal Bay Anticline and the two panels immediately to the west of it (Figure 2). In the west-facing panels above and below the Side Harbour thrust, they are mostly found in the lower Pennys Brook Formation and immediately above and below the Sparrow Cove Formation. However, in the east-facing tectonic panel containing the Seal Bay Anticline (Figure 2), the best pseudoporphyroblast development is seen in the strata of the Omega Point Formation, well below its boundary with the overlying Sparrow Cove Formation. Secondary alteration minerals are generally poorly developed in the easternmost part of the Seal Bay Brook–West Arm Brook area.

An extensive hematite-rich alteration of the basalt lenticles in the upper Pennys Brook Formation is a particularly notable feature of the Seal Bay Brook area. It may be significant that the Badger Bay Brook basalt, the westernmost Pennys Brook lenticle shown in Figure 4, is also locally reddened and affected by this type of alteration. Although porphyroblastesis of Pennys Brook and older turbidites is a widespread phenomenon developed sporadically throughout the ca. 600 km2 outcrop area of the Wild Bight Group, the hematization, pyritization and quartz veining of Pennys Brook basalt is a generally uncommon alteration feature.

Silicification and associated iron oxidation of mafic volcanic rocks within, and immediately below, the Omega Point Formation is so ubiquitous as to be a characteristic feature of the lava flows in this part of Wild Bight Group. In the Side Harbour Pond area (A-A' in Figure 2), jasper- and hematite-bearing pillow lavas display abundant interstitial red chert and are closely associated with intervals of siliceous red argillite and bedded chert. At the estuary of Seal Bay Brook and eastward along Seal Bay Bottom, such altered basalts occur in slump sheets or are variably disaggregated in sand-matrix debrites, which are situated stratigraphically below thin-bedded turbidite successions marked by beds of red replacement chert. In the upper Seal Bay Brook area (northwest of B-B' in Figure 2), green, epidote- and chlorite-bearing vesicular basalts alternate with red pillow lava horizons, enriched in hematite and disseminated jasper.

Age of Rock Alteration in the Lower and Upper Wild Bight Group

Basalts near Big Lewis Lake, Seal Bay Brook and Side Harbour (Swinden *et al.*, 1990) are strongly altered in the structural footwall sequence of Swinden and Jenner's (1992) West Arm Brook Thrust and the Side Harbour thrust (Figures 2 and 4). Many of these altered non-magnetic basalts presumably belong to the Pennys Brook Formation and occur at considerable distances structurally below the Point Leamington massive sulphide deposit. Some of the Big Lewis Lake, Seal Bay Brook and Side Harbour basalts are tectonically intercalated with Omega Point Formation volcanic rocks, which are geochemically similar to the New Bay Pond basalts in the hanging-wall of the West Arm Brook Thrust (Swinden *et al.*, 1990; B. McConnell, personal communication, 2000).

In Glovers Harbour-type volcanic rocks of the Wild Bight Group near the Lockport massive sulphide deposit, at least some of the basalt alteration is known to predate an alkali gabbro dated at ca. 486 Ma. In age-equivalent rocks of the lower Exploits Group at the Tea Arm massive sulphide prospect, the mineralization is contained in a rhyolite dated at ca. 486 Ma. It would be reasonable to presume that the alteration of lower Wild Bight Group strata at the Point Leamington massive sulphide deposit (Walker and Collins, 1988) and near the Long Pond and Indian Cove stockwork sulphide zones (Swinden, 1988) may also be Early Ordovician. This conclusion implies that the depositional age of the altered basalts in the upper Wild Bight Group is younger than the alteration age of basalts in the lower Wild Bight Group. If this is correct, then the alteration of the Big Lewis Lake, Seal Bay Brook and Side Harbour basalts would be necessarily unrelated to the alteration of the older New Bay Pond basalts. Furthermore, these younger strata could not comprise the original stockwork that developed in the stratigraphic footwall of an Early Ordovician volcanogenic massive sulphide deposit.

TECTONIC ORIGIN OF HORSESHOE THRUSTS

In modern tectonic environments, horseshoe-shaped oblique-slip thrusts are characteristic of back arc, interarc or forearc basins, which were closed during an episode of subduction zone retreat in the early stages of arc-continent or microcontinent-continent collision (Royden, 1993). Here, the rate of subduction beneath the extended upper-plate island arc is typically faster than the overall rate of convergence of the lower plate with the upper plate. These geological conditions are commonly found in small tectonic plates (marginal basins or constricted oceans) where ridge-push at the spreading zone is overwhelmed by slab pull at the subduction zone. In this tectonic model, a remnant oceanic and microcontinental plate (e.g., mid Ordovician peri-Gondwana) encroaches on a craton's convergent margin (e.g., mid Ordovician Laurentia) by the process of contracting and partially destroying basins situated in the volcanic arcs and microcontinents of the encroaching lower plate, often at some distance from the trench and foredeep (of pericratonic Laurentia; *see* van Staal *et al.*, 1998).

It is common for the volcanic island arcs that originally fringed the microplate being subducted to subsequently act as rigid body indentors during regional collisional deformation (e.g., Lin *et al.*, 1994). Where the island-arc basins in the upper plate or the marginal oceanic basin in the lower plate are most contracted, orogen-parallel movement along the collisional suture (e.g., Northrup and Burchfiel, 1996) promotes arcuate strike-slip thrusting (Royden, 1993) and the lateral extrusion of thrust sheets (Ratschbacher *et al.*, 1991). Bivergent thrusts, which dip in the same and opposing directions as the fossil subduction zone, form in such sediment-dominated basins, especially where the partially-inverted basin fill is indented by a volcanic arc or a microcontinent. It is possible that these oblique-slip bivergent thrusts develop in crust decoupled from the mantle (Quinlan *et al.,* 1993).

Early Ordovician volcano-plutonic rocks probably acted as rigid body indentors during the folding and thrusting of the Middle Ordovician strata of the Wild Bight Group. These tectonic indentors are represented by a remnant volcanic-arc sequence in the lower Wild Bight Group (MacLachlan and Dunning, 1998a) and an arc-ophiolite plutonic suite in the South Lake Igneous Complex (MacLachlan and Dunning, 1998b; MacLachlan, 1999). Such rocks presently occur within, and near, a regional scale, folded imbricate fault zone, whose sole thrust marks the structural base of the middle and upper parts of the horseshoe-shaped thrust stack in the Seal Bay Brook–West Arm Brook area (Figure 4). There, and elsewhere (MacLachlan and O'Brien, 1998), the Early Ordovician rocks are mainly structurally detached from the rest of the group although, as evidenced by the primary thickness variation of the Pennys Brook turbidites in the footwall sequence, they may have possibly once underlain structural highs near the mid Ordovician margin of the Wild Bight–Exploits depositional basin (O'Brien, 1998).

The horseshoe-shaped thrust stack in the Seal Bay Brook–West Arm Brook area documents a large "south-over-north" displacement that is thought to relate to a regionally developed system of late D1 back thrusts. Such structures affect the Wild Bight Group (*see* B-B' in Figure 3) and adjacent units of the Exploits Subzone. The F2 cross folding of the horseshoe-shaped thrust zone is evident in Figure 2. The arcuate "south-over-north" thrust zone is thought to have formed prior to the northeast-trending faults and shear zones that produced localized northeastward translation and D2 lateral ejection of the group's Middle Ordovician strata farther west (O'Brien, 1998). As a corollary of these observations, early D1 horseshoe thrusts having "north-over-south" displacement could be expected elsewhere in the Wild Bight Group.

The regional horseshoe thrust illustrated in Figures 2 and 4 is interpreted to have originated during orogen-parallel sinistral movement along the Red Indian Line (i.e., when the colliding Exploits Subzone rocks moved northward and northeastward). This is compatible with the hanging-wall sequence of the Pennys Brook Formation moving northward over the footwall sequence of the Pennys Brook Formation. As both the convergence vector and tectonic transport direction are northward, the displacement is mainly dip–slip where the back thrusts have a general easterly trend (Figure 4). Where north–south-striking and west-dipping, the strike–slip component of offset on the imbricate thrusts is dextral. Where north–south-striking and east-dipping, the strike–slip component of offset on the imbricate thrusts is sinistral. In the schematic cross sections of the bivergent thrusts and reverse faults along the "sides" of the horseshoe-shaped structure, the writer postulates that west-dipping faults postdate east-dipping faults in the western part of the map area (A-A' in Figure 3) and that east-dipping faults postdate west-dipping faults in the eastern part of the map area (D-D' in Figure 3).

SUMMARY AND CONCLUSIONS

In the Seal Bay Brook–West Arm Brook area, Ordovician rocks of the Wild Bight Group comprise a complex lithotectonic sequence. An arcuate horseshoe-shaped thrust stack, which has a regional southwest dip in the west and a regional southeast dip in the east, displays three main structural and stratigraphic elements.

The first of these tectonic elements, a braided imbricate fault zone in the middle part of the thrust stack, occupies at least 30 km^2 of ground. In several places along the base of this imbricated sequence, discontinuous thrust sheets of folded Omega Point Formation and older parts of the Wild Bight Group are exposed.

These rocks are structurally underlain by the second element of the Wild Bight lithotectonic sequence. Mainly composed of right-way-up volcanic and sedimentary rocks, most strata in this approximately 70 km^2 tectonic panel belong to the Pennys Brook Formation. Pennys Brook strata at the top of the lower sequence occur inside the trace of a horseshoe-shaped sole thrust and are thus part of the regional footwall sequence. They contain some of the youngest known rocks of the Wild Bight Group in the area surveyed.

An equally extensive tectonic panel of similar Pennys Brook strata, which are also right-way-up, structurally overlies the main imbricate fault zone. This panel represents the third element of the Seal Bay Brook–West Arm Brook thrust stack. Extending from the valley of Badger Bay Brook southward and eastward to New Bay Pond, it occurs outside the folded trace of the structurally highest thrust and is thus part of the approximately 85 km^2 hanging-wall sequence.

In conclusion, the most widespread and youngest formation of the Wild Bight Group, the Pennys Brook Formation, is structurally duplicated across a regional fault zone that disposes fragments of some of the oldest and most extensively mineralized rock units in the group. The arcuate shape of the thrust stack is postulated to be a primary feature related to orogen-parallel displacement on oblique-slip reverse faults, although the concave back thrusts of the imbricate fault zone have been cross folded and further shortened by several generations of later minor folds.

ACKNOWLEDGMENTS

Angela Pickett and Leon Normore provided superb field assistance and enthusiastically helped with the geological surveying of the map area. We thank pilots from Universal Helicopters, Gander, for their very professional service in the transport of personnel and equipment to our remote camps. We also acknowledge Project Management staff for logistical support and excellent field communications. To the Abbott family of Gander and the Haggett family of Point Leamington, we express our kindest regards. Thanks are due to Lorne Ryan of the Geological Survey cartographic unit, who made the digital files for the figures, and Steven Colman-Sadd of the Regional Geology Section, who carried out the scientific review.

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